Karagozian & Case

B-07-149

Karagozian & Case
2550 N. Hollywood Way
Suite 500
Burbank, CA 91505
(818) 240-1919
www.kcse.com

Satellite Office:
Albuquerque, NM
(505) 291-4489

Blast Effects Analysis of Convault Aboveground Storage Tank (AST)

By:
Leonardo Torres
Paul Carpenter
Joe Magallanes

Prepared for:
Convault Inc.

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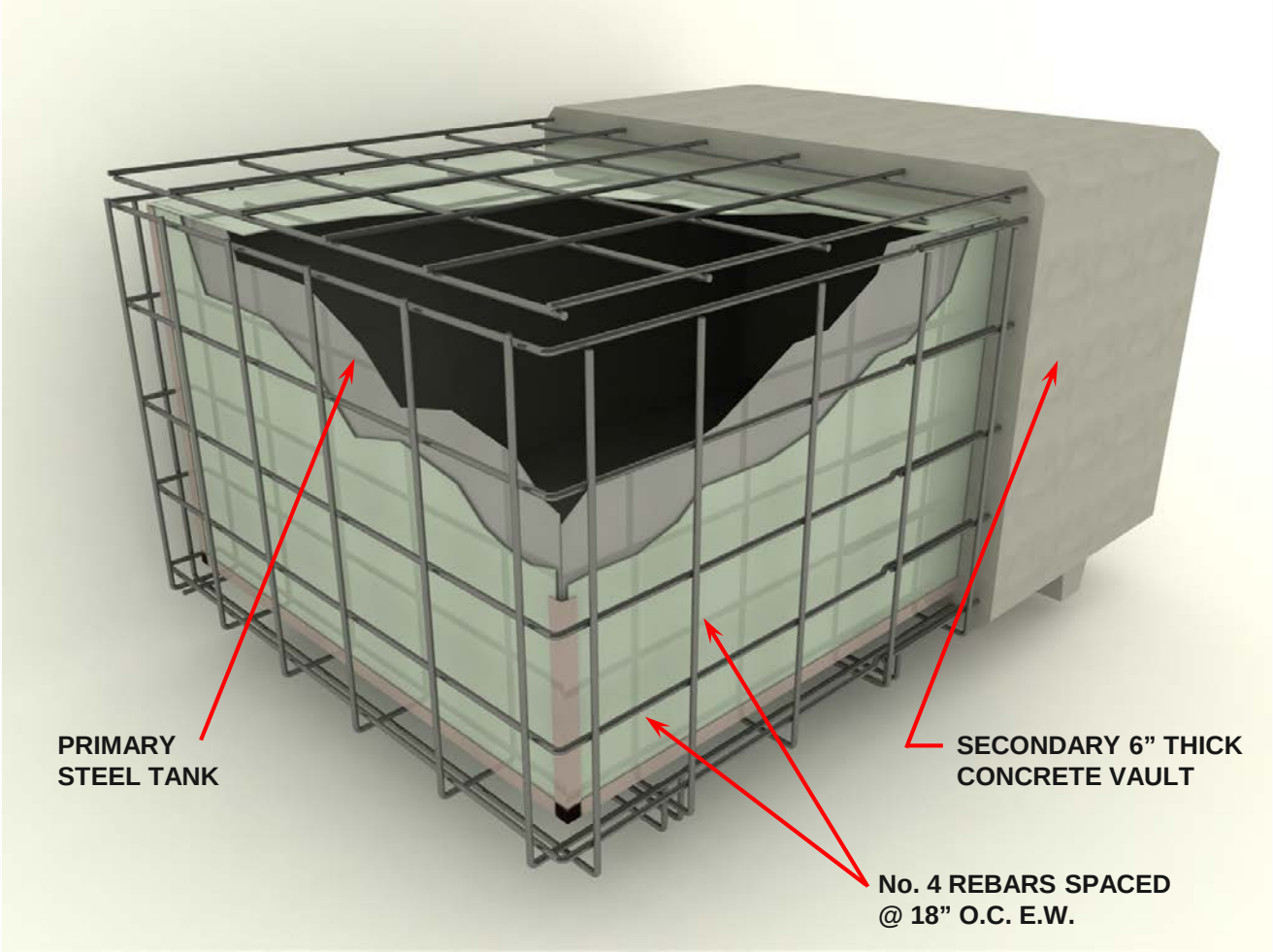
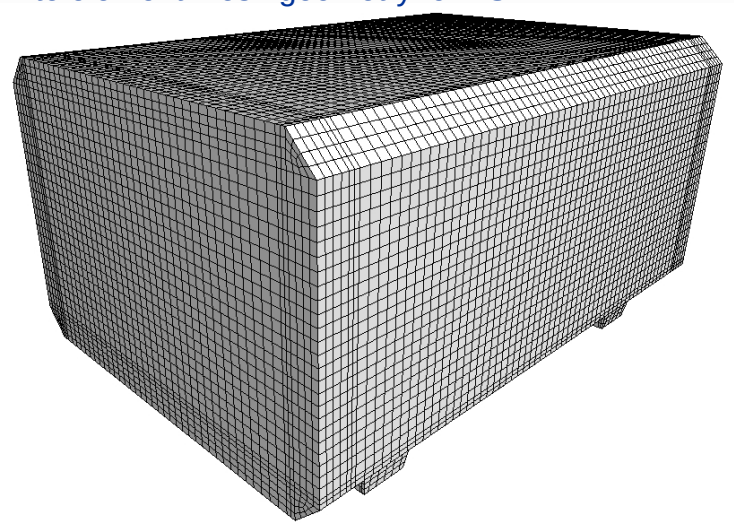
2000 gallon Convault AST



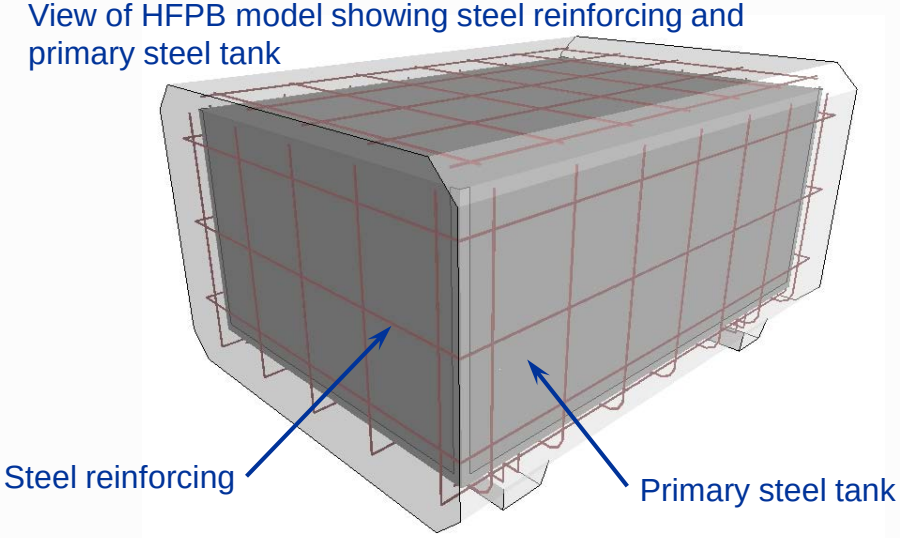
High Fidelity Physics Based (HFPB) Model of Convault AST

- Concrete is modeled using solid elements measuring roughly 2” x 2” x 2”
- Steel reinforcement is modeled using beam elements merged together with concrete elements
- Primary steel tank, steel angles and interior steel frames are modeled using shell elements
- Roughly half the calculations were performed with the AST half full of liquid. The liquid is modeled using solid elements with the material properties of water

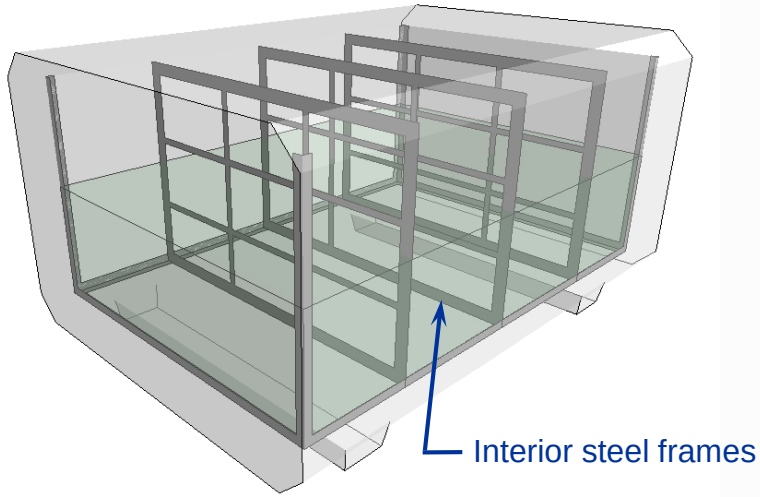
Finite element mesh geometry for AST



View of HFPB model showing steel reinforcing and primary steel tank



AST half-full of liquid showing interior steel frames



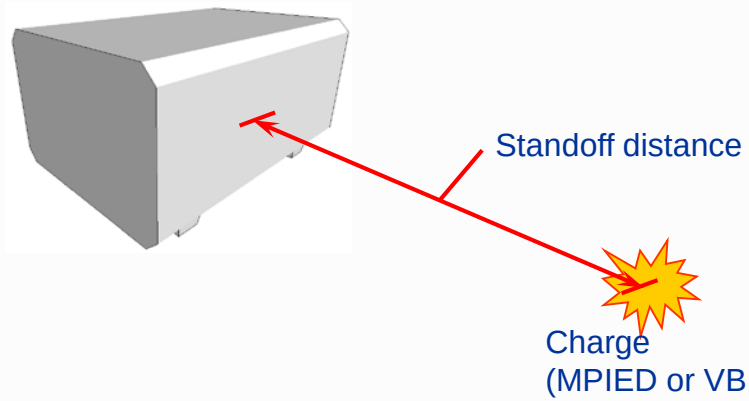
Explosive Threat Scenarios

- **Man-portable improvised explosive device (MPIED)**
  - *Representative of a charge size that can be carried in a suitcase*
  - *Approximately equivalent to a charge weight of 50 pounds of TNT*
  - *Standoff distances ranged from 6 inches to 20 feet*
- **Vehicle-born improvised explosive device (VBIED)**
  - *Representative of a charge size that can be carried in a compact sedan*
  - *Approximately equivalent to a charge weight of 500 pounds of TNT*
  - *Standoff distances ranged from 5 feet to 100 feet*
- **Vapor cloud explosion (VCE)**
  - *Upper bound estimate of load expected in the event of an accidental vapor cloud explosion*

Bomb Threat Stand-Off Distances

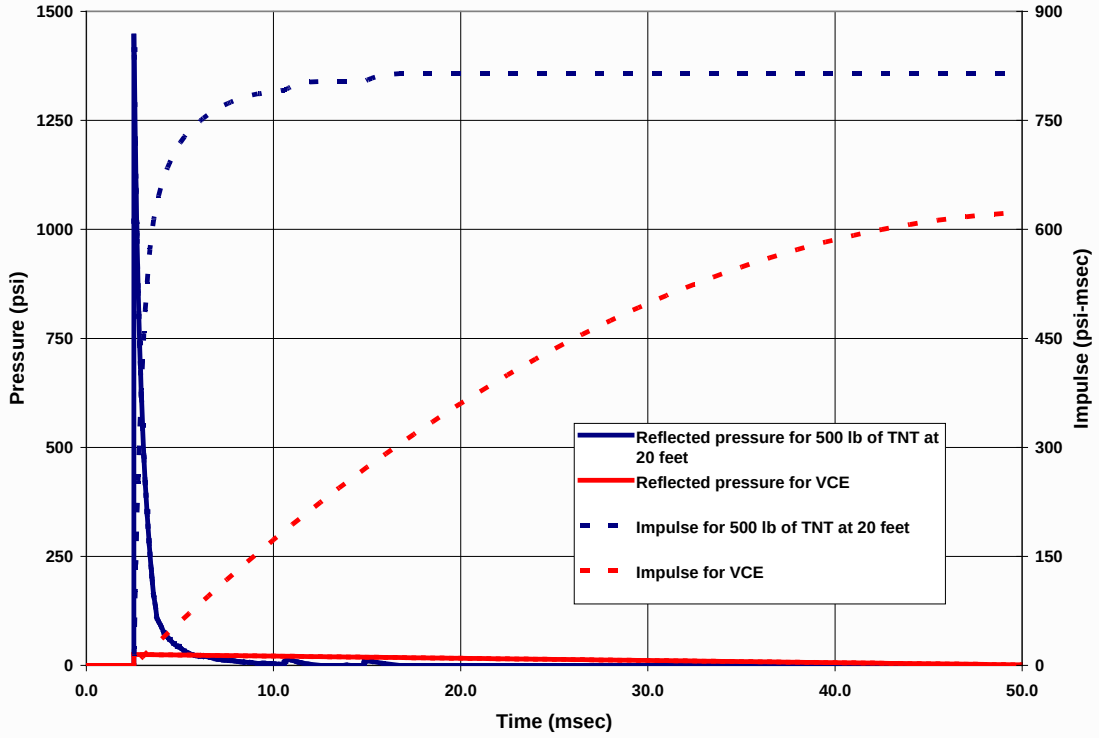
Threat Description		Explosives Capacity[1] (TNT Equivalent)	Building Evacuation Distance[2]	Outdoor Evacuation Distance[3]
	Pipe Bomb	5 LBS/ 2.3 KG	70 FT/ 21 M	850 FT/ 259 M
	Briefcase/ Suitcase Bomb	50 LBS/ 23 KG	150 FT/ 46 M	1,850 FT/ 564 M
	Compact Sedan	500 LBS/ 227 KG	320 FT/ 98 M	1,500 FT/ 457 M
	Sedan	1,000 LBS/ 454 KG	400 FT/ 122 M	1,750 FT/ 533 M
	Passenger/ Cargo Van	4,000 LBS/ 1,814 KG	600 FT/ 183 M	2,750 FT/ 838 M
	Small Moving Van/ Delivery Truck	10,000 LBS/ 4,536 KG	860 FT/ 262 M	3,750 FT/ 1,143 M
	Moving Van/ Water Truck	30,000 LBS/ 13,608 KG	1,240 FT/ 378 M	6,500 FT/ 1,981 M
	Semi-Trailer	60,000 LBS/ 27,216 KG	1,500 FT/ 457 M	7,000 FT/ 2,134 M

Source: National Counterterrorism Center (NCTC)



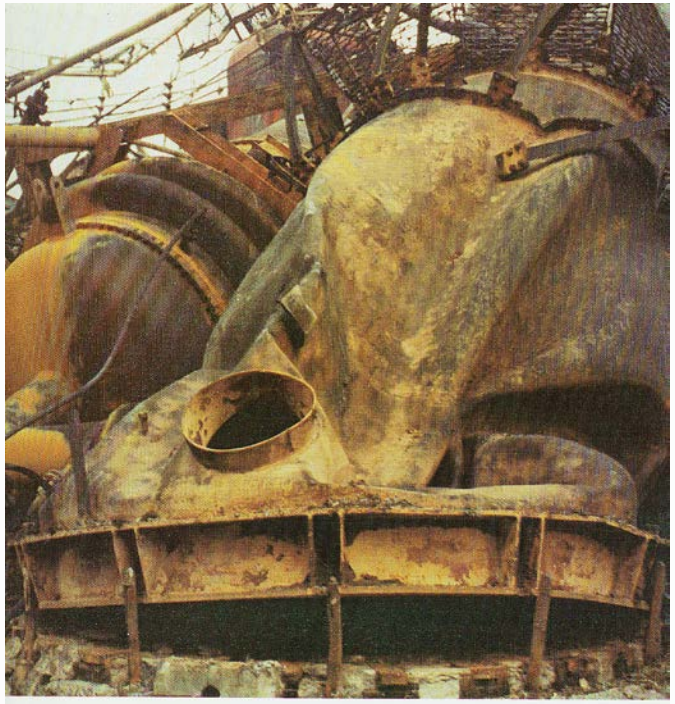
Comparison of HE Loading to Loading from Vapor Cloud Explosion

- **HE Loading (500 lb TNT at 20 foot standoff)**
  - *Max Pressure: 1444 psi*
  - *Max Impulse: 815 psi-msec*
  - *Short duration: < 10 msec*
- **VCE**
  - *Max Pressure: 25 psi*
  - *Max Impulse: 625 psi-msec*
  - *Long duration: ~ 50 msec*

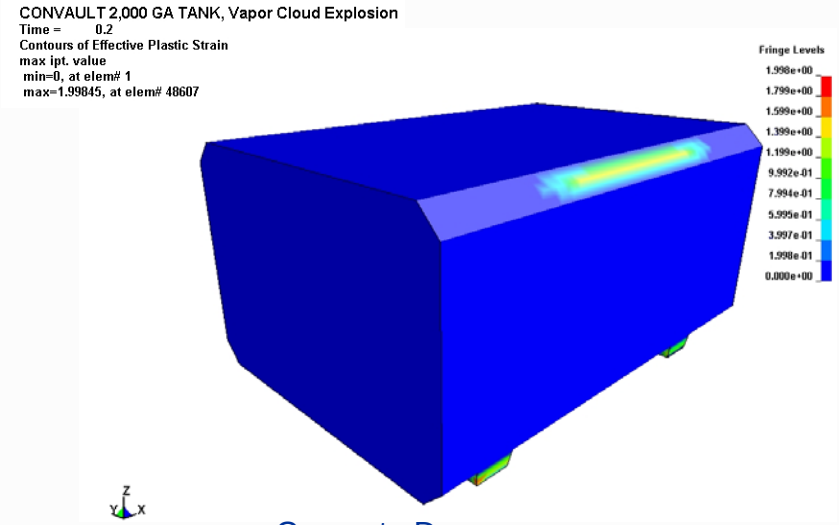


Results for VCE

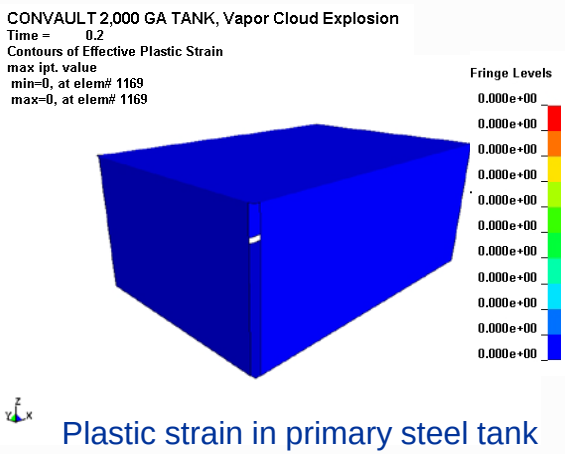
- **Performed exceptionally well**
  - ***Minor concrete damage***
  - ***Little to no plastic strain in primary steel tank and internal frames***
- **Exterior concrete layer greatly enhances performance of AST**



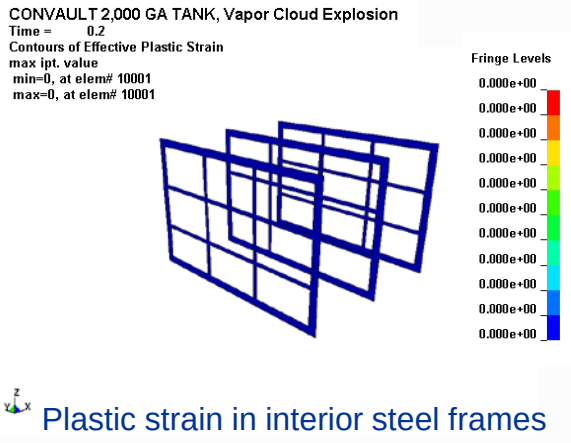
Example of damage to unprotected steel pressure vessel failure following a large VCE



Concrete Damage



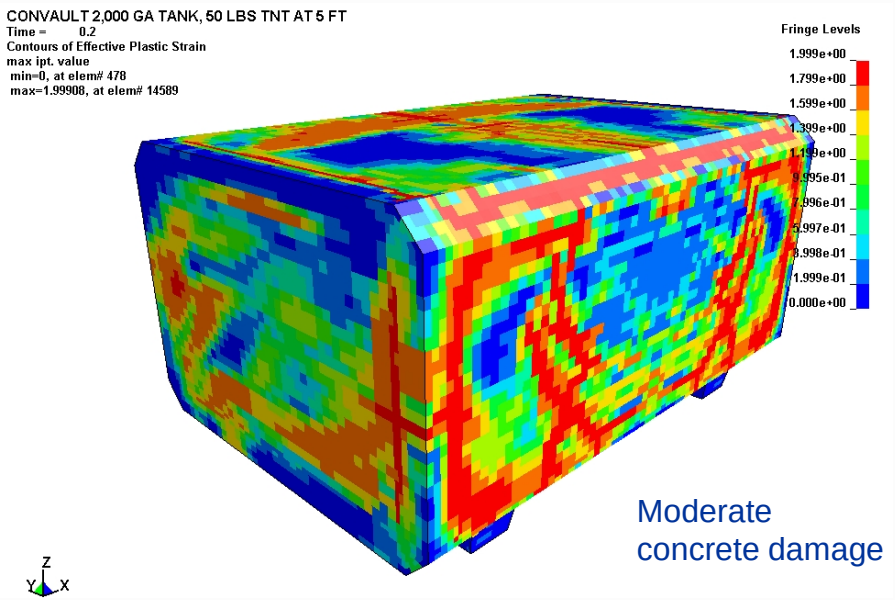
Plastic strain in primary steel tank



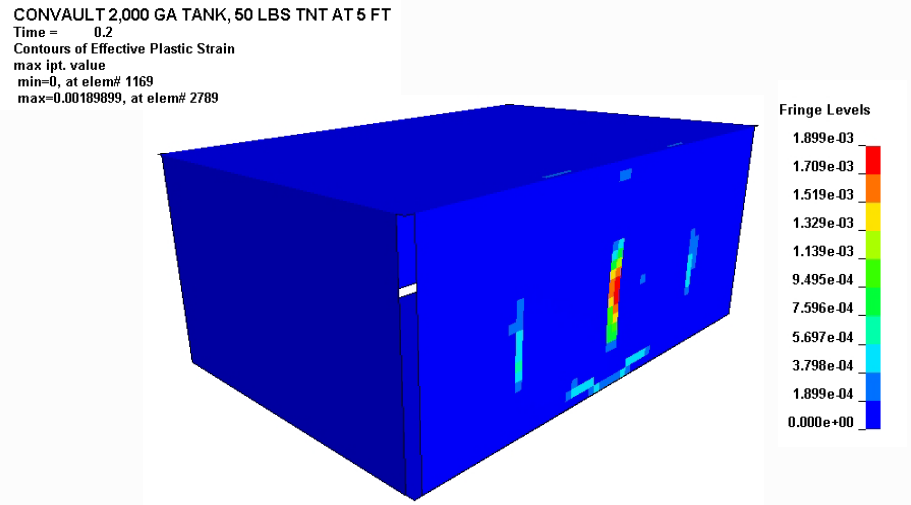
Plastic strain in interior steel frames

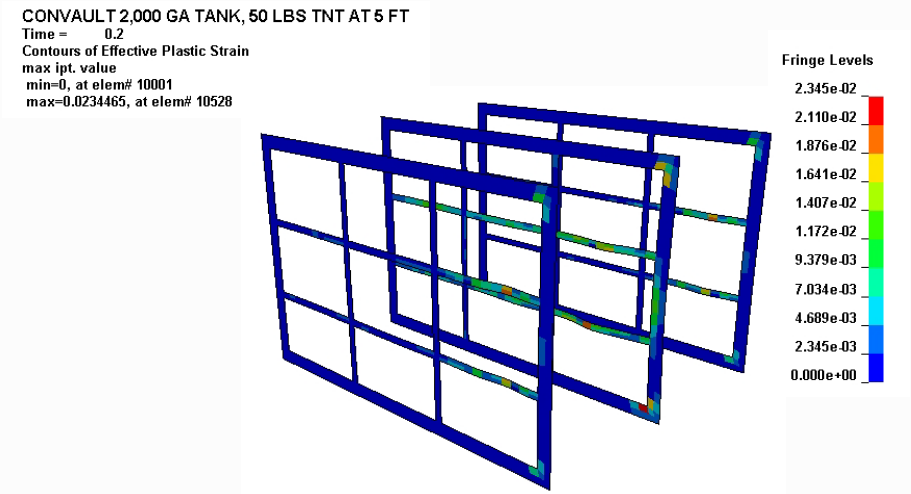
Response to MPIED at 5' Standoff

- 50 pounds of TNT at a close standoff distance (5 feet)
- Moderate damage to the exterior concrete. Cracking can be expected, however will remain intact
- Damage incurred by concrete attenuates load imparted to steel tank
  - *Very minor plastic strains measured in primary steel tank and interior frames (less than 1%)*
- Very minor overall displacement of tank (less than 1")



Moderate concrete damage





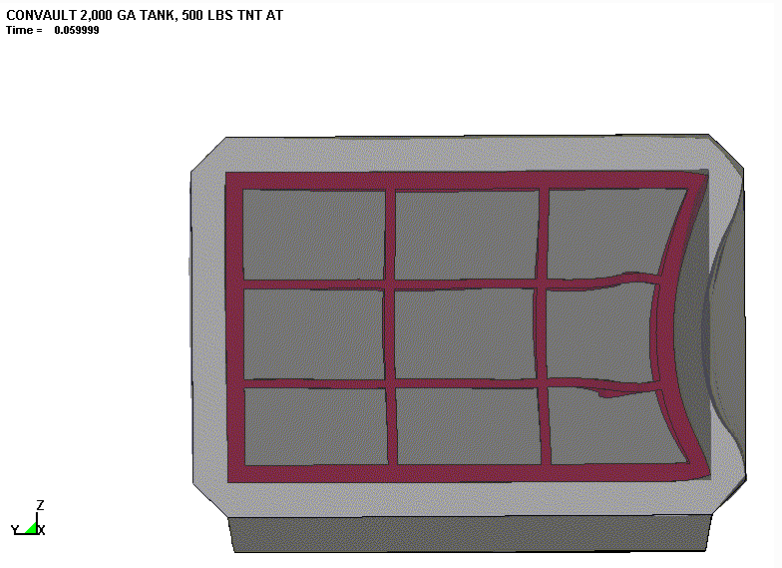
Low deformation and plastic strain on primary steel tank and internal steel frames

Rigid Body Displacement

- **Two basic uses for Convault AST's**
  - ***Vehicle fueling***
    - **Fuel lines attached**
  - ***Diesel fuel storage for generator***
    - **Pipes used to provide connection to generator equipment**
- **Large displacements only seen when the AST is loaded with 500 pound charge at close standoff distances of 10 feet or less**

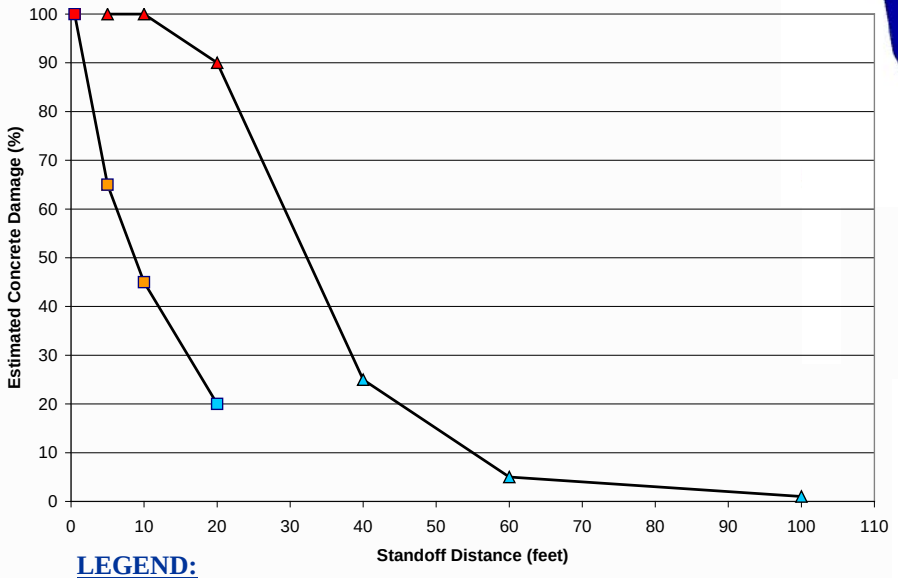
Rigid body displacements for MPIED and VBIED loads for the half-full AST

Case	Run	Loading Description		Rigid body displacement
		Weight (lbs)	Standoff (feet)	
MPIED	Run04	50	5	0.6 inches
	Run07	50	10	< 0.1 inches
	Run01	50	20	< 0.1 inches
VBIED	Run03	500	20	1.1 inches
	Run10	500	40	< 0.1 inches
	Run11	500	60	< 0.1 inches
	Run12	500	100	< 0.1 inches



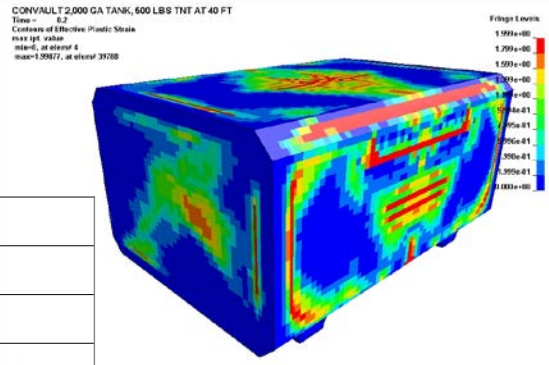
Concrete Damage

- **Estimated concrete damage**
  - *High: 70% or more*
  - *Moderate: 30% to 70%*
  - *Low: 30% or less*

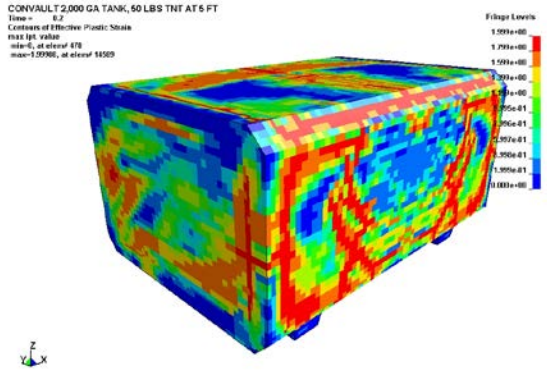


Estimated concrete damage levels versus standoff distance

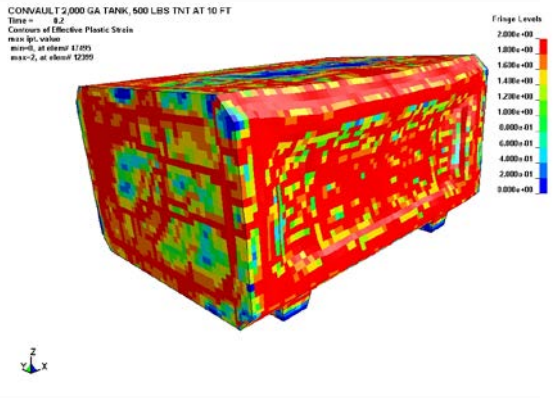
Low concrete damage (500 pounds of TNT at 40-foot standoff)

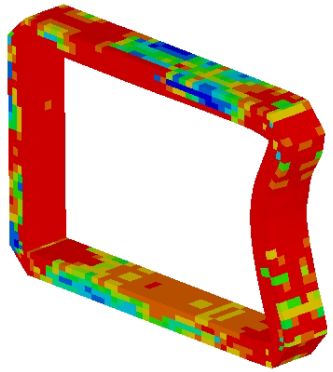


Moderate concrete damage (50 pounds of TNT at 5-foot standoff)



High concrete damage (500 pounds of TNT at 10-foot standoff)

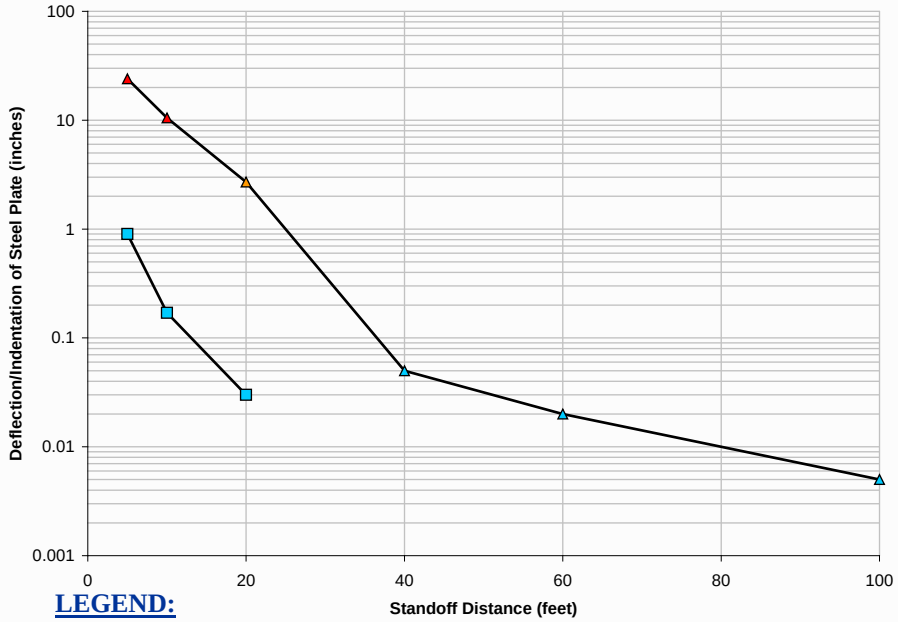




Section through AST

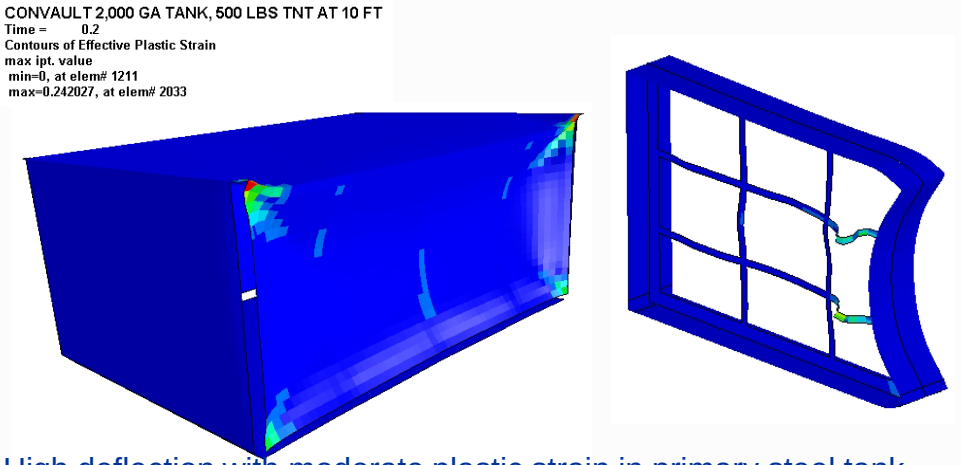
Steel tank damage

- **Estimated steel tank damage based on deflection of tank's front face and peak plastic strains**
- **Analysis of low standoff distances of 5 and 10 feet for VBIED shows moderate to high peak deflections and strains – borderline of whether tank can support contents**



Rigid body displacements for MPIED and VBIED loads for the half-full AST

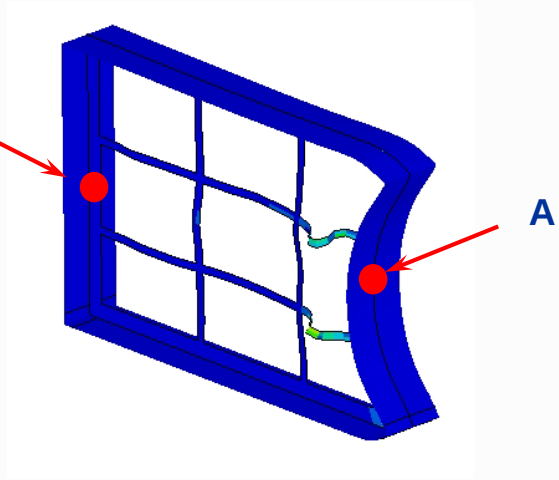
Case	Run	Loading Description		Peak Deflection of Mid-Front Side (in)	Peak Strain on Front Face (%)
		TNT (lb)	Standoff (ft)		
MPIED	04	50	5	0.2	0.1
	07	50	10	0.1	0
	01	50	20	0.1	0
VBIED	06	500	5	16	26.4
	09	500	10	6.4	11.6
	03	500	20	1.6	0.6
	10	500	40	0.1	0
	11	500	60	0.1	0
	12	500	100	0	0

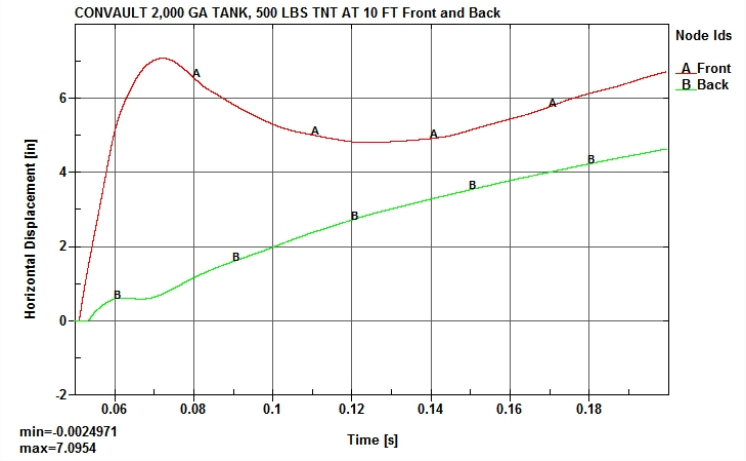


High deflection with moderate plastic strain in primary steel tank and internal frames (500 pounds of TNT at 10 foot standoff)

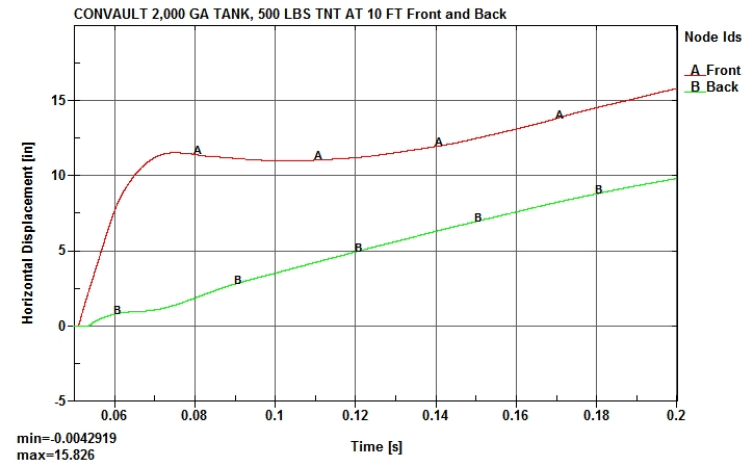
Comparison of half-full and no water

- **Half-full AST performed better than empty**
  - ***Added mass helps to limit rigid body displacement***
  - ***Added mass and pressure provided by fluid inside AST help to limit inward deflection of front face***





Displacement of front and back faces
(AST – half-full with liquid)



Displacement of front and back faces
(AST – empty)

Summary

- **Secondary concrete tank provides attenuation of explosive loads and protects primary steel tank**
  - ***Performance of Convault tank likely to compare favorably to competitors' tanks without exterior concrete shell***
- **Standoff**
  - ***AST performs well when adequate standoff distances provided***
    - **MPIED: greater than 5 feet**
    - **VBIED: greater than 20 feet**

Example of standoff distance enforced with the use of bollards